UNDERGROUND WATER IN SOUTH-EASTERN BECHUANALAND.*

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In almost every part of South Africa the question of water supply is of the utmost importance, and the area known as Bechuanaland is by no means an exception.

Nowhere are there any perennial streams, and in comparatively few spots are there facilities for storage of flood-water, that is by individual effort, unless with great difficulty and at great expense; furthermore, springs and fountains are by no means as numerous as in the area south of the Orange River.

As a necessary consequence, if we except the case of storage of rain-water, the supplies are obtained principally from wells and, to a lesser degree, from boreholes. The number of the latter is increasing but slowly, for many reasons have prevented the more extensive utilisation of drills.

The volume of water obtainable from these artificial openings, even in cases where the pumping is effected by wind-power, is strictly limited, and irrigation on any scale is quite impossible.

In the following the author will endeavour, firstly, to point out the considerable influence of the geological formation on the storage of underground water; and secondly, will consider the potentialities of such a supply. In this paper the term South-eastern Bechuanaland will be taken to include the fiscal divisions of Mafeking and Vryburg as far to the west as Kuruman. Doubtless much will be applicable to the areas adjoining.

Natural features.—The area consists of a rather flat, or but slightly undulating, country of rather monotonous aspect.

Around the town of Vryburg the altitude is generally close on 4,000 feet above sea-level, but northwards there is a gentle rise of

* *Communicated with the permission of the Geological Commission.*

from 300 to 600 feet towards the boundary dividing Vryburg from Mafeking, and this constitutes the watershed. Beyond this, both to the north and north-west, we find a gently rolling country with a gradual fall towards the Kalahari.

On the south drainage is effected by the Dry Harts River, while on the north are various tributaries of the Molopo, namely, the Mosita, Setlagoli, and Maretsani Rivers, and the Ramathlabama Spruit. To the west are the Mashowing and Kuruman Rivers.

In the east there is comparatively little vegetation, most of the timber having been cut down for use in the Kimberley mines or destroyed by bush-fires, but west of the railway, and at a distance of from 20 to 30 miles from it, the country is usually covered with large thorn trees, while the ground is thickly grassed.

The existence of such an abundant vegetation in a district where surface-water is usually absent invariably impresses the traveller with amazement.

Geology.—Over almost the entire division of Mafeking, and westwards through Genesa, the basement rock is granite and gneiss, but exposures are not frequent on account of the considerable depth of reddish-yellow sandy soil produced by their disintegration. To the north and north-east of Vryburg, and again at Mafeking, are extensive flats formed by diabases and amygdaloidal rocks, these being later than the granite and having a considerable development in the adjoining portions of the Transvaal.

At Vryburg is the north-easterly termination of the Campbell Rand limestone and dolomite—a formation that constitutes the immense Kaap Plateau. It stretches westwards as far as Kuruman, and then turns northwards, passing in a broad belt through Morokwen towards the Molopo River and the Bechuanaland Protectorate.

At Vryburg and further south, in the Dry Harts River valley, there are depressions in the older rocks, that have been filled in with shales and boulder-clay belonging to the Dwyka formation.

Subsoil water.—Rain falls in the summer-time principally, and commonly in the form of thunder-showers.

The Dry Harts River runs during a portion of the year, but north of the watershed the rivers only come down after continued thunderstorms. The flow is, however, soon lost in the sand of the riverbeds, and in the Molopo, below its junction with the Setlagoli River, running water is seldom found.

By digging shallow pits in the beds of the rivers the natives obtain water; curiously enough, water appears to be absent in certain reaches and is found again at points further down the valleys. Why this should be so is not evident; possibly the water may make its way beneath one or other of the banks either along an old and now-buried channel or along cracks and fissures in the rocks.

According to Penning,* a somewhat analogous phenomenon exists in the lower portion of the Molopo River north-westward from Kuruman; his notes on the underground water of this part of the Kalahari, and also of the region still further to the west, afford very considerable and interesting information.

A rather curious feature, confined to the granite area, is the occurrence of what are known as "sand-wells." By sinking a pit in the sand a little water collects at the bottom; on deepening the excavation the water-level does not remain stationary, but falls considerably, and the supply is soon exhausted. These "sand-wells," curiously enough, are often productive at points quite high up on the sides of granitic ridges.

Ground water.—From the soil the seepage gradually makes its way downwards into the underlying rock, and the depth to which the water will penetrate will depend upon the nature of the rock, its porosity, degree of decomposition, the existence of joints, &c.

In addition there is the slow but regular movement of the ground water towards those parts of the country having a lesser elevation. In this the movement is aided by fissures, channels, or "veins" of varying width, along which the water can more readily travel than through the pores of the rock. Though it is an open question whether these "veins," which make water-boring in many cases so uncertain an operation, can be located by human agency, there are, nevertheless, various surface indications that may influence a person in making a selection of a site.

(1) *Topography.*—It is usual, of course, to choose a site at as low a level as will be convenient, yet sometimes, paradoxical as it might appear, this may not be the best situation. For example, supposing we have the common case of a wide flat crossed by a deepish river-valley, it is not unusual to find that a well sunk near the centre of the flat will give a better supply, and that also at a shallower depth, than will be obtained at points on the slope not far from the river-bed. This is due to the rapid fall of the water-table towards the line of drainage below the river channel.

* W. H. Penning, "Gold and Diamonds," chapters iv. and v., London, 1901.

As far as possible ridges and watersheds should be avoided, for the area that can be drained by a well in such a position is invariably small, and the proportion of rainfall absorbed by the soil is much lower than on the flats. A troublesome strip of country is the main watershed, and the wells along it are considerably deeper than elsewhere. The normal scarcity of water is intensified by the existence of a belt of compact quartz-porphyry.

(2) *Dykes, faults,* &c.—It is not uncommon to find shrubs clustered thickly together along a certain line with such regularity as to produce a narrow belt resembling an artificial plantation. These "aars," as the Dutch farmers call them, may extend in straight lines for miles, and are due to several causes.

Basic igneous dykes may give rise to these phenomena, and in most cases wells sunk on their outcrops give good supplies of water. The effect may be produced by quartz-reefs, but they are not very plentiful here, and the underground circulation of water is therefore not appreciably influenced by them.

Sometimes, on sinking, no foreign rock is met with, but there is a zone of crushed and decomposed material along which the water makes its way; this is not unusual in the granite area.

In the dolomite region such "aars" form narrow ridges a few feet higher than the surrounding country; they are generally capped with calcareous tufa, and support a thicker vegetation than round about.

(3) *Calcareous tufa.*—Patches of soil are very frequently found covered by a deposit of calcareous tufa of greater or less thickness. In many cases this points to the presence of water at no great depth.

In the dolomite area, and again in that occupied by diabase and amygdaloid, the carbonate of lime is derived by direct solution from the former rock, and by the decomposition of the minerals in the latter. Moisture containing the carbonate in solution is drawn up to the surface by capillary forces, and by evaporation the tufa is formed. In many cases the rims and floors of pans are composed of a similar deposit.

Sometimes, however, the carbonate of lime is brought down by rivers which take their rise in a dolomite area, and the tufa so formed is deposited upon any kind of rock, and may therefore be no indicator of underground water.

(4) *Pans and vleys.*—These depressions are extremely numerous throughout the district, and vary from a few yards to over a mile in diameter; they exist on nearly every formation.

These pans hold water for a certain period during the rainy season; all of them dry up during the winter.

Experience has shown that a well sunk within or upon the edge of a pan usually gives a good supply of water at a shallow depth. The reasons for this are threefold: firstly, the underlying rock, being kept moist, tends in consequence to decompose and become more porous; secondly, as the level of the pan is often at quite an appreciable depth below the surrounding country, moisture gravitates towards the depression; and thirdly, owing to seepage from the pan itself, the level of the water-table beneath and immediately around the pan is usually higher than elsewhere.

For abundance of supply it would be difficult to beat the little depression on the farm Water Pan between Vryburg and Genesa; the underlying rock consists of a very decomposed and highly porous granite.

Brak pans, which are so characteristic of that portion of the Kalahari north of Upington, are practically unrepresented in this district; the exceptions are Groot and Klein Chwaing.

(5) *The junction of two formations.*—It is rather surprising that so little advantage is taken of the occurrence of water at the junction of two dissimilar sets of rocks. For example, the base of the Black Reef Series is markedly water-bearing, and fine springs occur at Vryburg and at Motiton.

There is one drawback to boring, namely, the excessively hard formation, which is almost impenetrable with ordinary drills.

Effect of the formation.—Over most of Bechuanaland the soil is sandy and of considerable depth, yet there appears to be but little of the water stored in it that can be made available. Consequently it is to the underlying rock that one has to turn, and as the nature of it may vary it is of great importance to discover the effect of the geological formation.

This will be briefly considered below :—

(*a*) *Granite and gneiss.*—This formation is hardly ever well exposed, and is usually covered with a mantle of reddish sandy soil.

As a rule the rock is a well-foliated muscovite-granite or muscovite-gneiss, with the foliation planes dipping at a high angle. The rock may be veined by pegmatites or traversed by quartz-reefs, both of which will probably influence the movements of underground water.

The granite and gneiss are more or less decomposed, and this alteration extends below the surface to a rather variable depth; the more micaceous gneissic varieties are usually altered to a greater degree than the compact unfoliated granites.

The reason is to be sought for in the different rates of expansion and contraction of the mineral constituents, by which planes of weakness are developed in the rock.

The very well-banded gneisses, with regular layers of quartz, felspar, mica, or hornblende, may have a high degree of fissility imparted to them through this process, aided by mineral decomposition. This condition is favourable for the penetration and retention of rain-water.

In boring, as long as the core brought up shows cavities and fissures, or the felspars are clouded or kaolinised, there is always a possibility of obtaining water. If, however, the core shows a perfectly sound, fresh, compact granite, it may be advisable to stop. In some cases the apparently solid rock has contained numerous minute cavities, hardly visible to the naked eye, and the borehole has yielded a considerable supply.

The more compact varieties of granite—and in this category we may include quartz-porphyry—will in most cases yield but little or no water. A formation of quartz-porphyry, such as that between Vryburg and Genesa, should as far as possible be avoided.

In boring or sinking spots should not be chosen where the granitic rock forms marked outcrops, and by preference sites should be selected where there are pans on the formation.

Generally speaking, the granite is a most uncertain rock in which to bore for water, and failures may continually be expected.

A diamond drill is the best for the purpose, as a jumper will often be unable to penetrate the less weathered varieties unless with great difficulty.

(*b*) *The diabase formation.*—This commonly forms flattish ground, and from it excellent supplies of water are obtained as a rule, sometimes from remarkably shallow depths. Especially is this so in depressions and pans and along stream-courses.

The formation, which is composed principally of igneous material, consists of layers of differing composition and texture, while much of the lava is amygdaloidal.

Down to a certain depth the diabase is full of cavities and fissures, but beyond that, at a distance of a few hundred feet below the surface, the rock becomes massive, and the finer-grained varieties may be absolutely waterless. We have, for example, a dry borehole over 500 feet deep in this formation at Vryburg Station.

(*c*) *The dolomite.*—This, as a rule, provides the best water supply, and fortunately is a formation of great thickness and one covering a vast area.

Water is usually met with not many feet below the surface, and on the flats between Vryburg and Kuruman there are several places where open water exists all the year round. Springs are not uncommon, and from them in not a few places abundant, and in some cases inexhaustible, supplies of water have been obtained.

The rock is well bedded and traversed by numerous joints, which have often been widened by atmospheric agencies and solution.

This produces a condition favourable to the downward passage of water; but if the process has gone on extensively, it may lead to the transference of the water to deeper levels.

There is no evidence as yet to show whether the movement of the underground water in the dolomite is considerable or rapid. This is a point of the utmost importance, for the rainfall in the east is very much higher than that in the west, and any transference of water from east to west will increase the underground supply in the region of lower rainfall.

There is a prevalent opinion that an underground river exists beneath the Kaap Plateau; an examination of the Kuruman district will probably give much information about the movements of water in the dolomite.

There are numerous layers and concretions of quartzite and chert in the dolomite which may render boring operations costly and laborious.

(*d*) *Other formations.*—The Dwyka formation, although of a very clayey nature, gives a fair supply of water within the town of Vryburg. The water is, however, hard, and has a faintly brackish flavour.

Certain chloritic slates and phyllites associated with magnetic-quartzites give excellent supplies, *e.g.*, at Kraaipan, but it is not often that advantage can be taken of these beds.

It is clear that however water-bearing a geological formation may be, there is always a limit to the amount that can be removed from it; therefore it is essential that we should consider the influences that tend towards the accumulation of water underground.

(1) *Rainfall.*—This is by far the most important factor, and it is unfortunate that records are available for but a few stations and date back for only a short period. When the great fluctuation in the value of the annual rainfall is taken into account, it is clear that a long series of continuous observations will be required before anything approaching the true mean can be obtained.

The following values are therefore only approximations: Mafeking, 26 inches; Vryburg, 24; Groot Boetsap (on the Kaap Plateau), 23; Campbell, 15; Griqua Town, 16; and Kimberley, 20.

There are no records of observations from Kuruman or from points further to the north or west, but from an examination of the curves of mean annual rainfall, which trend somewhat north and south, there appears to be a considerable falling off in the amount of rain as one proceeds towards the Southern Kalahari.

This rainfall occurs almost entirely during the four summer months, and for the rest of the year the amounts registered are comparatively insignificant.

There can be no doubt that in former times, within the last century, the rainfall over this portion of South Africa was much greater than that of the present day; this is a matter of the highest importance.

Though the testimony of the earlier travellers is neither unanimous nor conclusive, the existence of river gravels at levels far above the present river-beds, and the deep cuttings made by the rivers themselves through ridges of hard rock, show that at the present day the rate of excavation and erosion is very much smaller than was the case in times past.

Whether the present diminution is merely a temporary one, to be followed by a gradual return to former conditions, is not by any means evident; but it will be best in our considerations to ignore such a possibility.

Of all this quantity of water that falls upon the surface of the ground, none of it, if we except the Dry Harts River, makes its way to the sea; that is, the run-off over this area is *nil.* Since practically there is no loss in this way, the whole of the rainfall will have to be accounted for by the processes of storage, evaporation, and transpiration; and while the addition of water to the subsoil can take place during a very small fraction of the year only, its removal goes on day after day throughout that period.

(2) *Penetrative power of water.*—It is a commonly noticed fact that after a thunderstorm of the average intensity the soil is still quite dry at a depth of a few inches below the surface, the precise distance varying for different soils.

The downward passage of the rain is greatly influenced by the porosity of the soil, *i.e.*, the ratio of the space between the sand-grains to the volume occupied by the sand itself; the larger these grains are the more rapidly does the water sink down. During, and immediately after, rain capillary action aids gravity, but as soon as the surface soil becomes drier than that below the action is reversed and the flow due to capillarity is upwards.

Hence the immense importance of periods of prolonged humidity, even if they are followed by intervals of lesser rainfall. This has been shown clearly by experiment * as well.

Along ridges and watersheds very little moisture is able to penetrate the soil, but in hollows and valleys the conditions are very much more favourable.

(3) *Evaporation and transpiration.*—By far the greater loss must occur directly from the surface, more especially as the rain falls during the heat of summer. The rate of evaporation depends not so much upon the temperature as upon the humidity of the air. There are no records available for this area, but at Kimberley, where the conditions are very similar, the mean annual humidity has the low value of 55 per cent.

Not only does evaporation take place directly from the surface after rainfall, but moisture is brought up from below ground by capillary action and so dissipated; the formation of calcareous tufa by this means has already been noted.

Some experiments made by Prof. F. H. King † show that the capillary movements of water are considerable even at a distance of 4 feet below ground; hence moisture is readily brought up from such a depth and evaporated. The importance of the rapid descent of the moisture through the soil is thus made apparent. They also indicate what has been proved in other ways, that, in the case of light showers, all the water is brought back to the surface and evaporated before it can get below the critical depth. Another source of loss is the transpiration of moisture by vegetation. Bechuanaland is fairly thickly clothed, and the roots of some of the thorn trees descend to depths of over 80 feet in search of nutriment. The amount of moisture transpired by a tree of average size is estimated at from 2 to 2½ gallons daily, but I am unable to obtain any figures for the transpiration losses per square mile of wooded country. The removal of water by vegetation must, however, take place on an immense scale annually.

Proportion of rainfall retained.—From the preceding paragraphs it is clear that this depends upon quite a number of factors, *e.g.*, whether the rainfall is above or below the mean, upon the porosity of the soil and the rock underlying, upon the depth down to decomposed material and thence to unfissured rock, upon the slope of the surface, upon the amount of vegetation it supports, &c.

I think, though, that if we consider the annual rainfall to be

* Prestwich, "Water Supply of London," p. 113, 1895.

† King, "Nineteenth Annual Report United States Geological Survey," vol. ii., p. 85, &c., 1899.

nearly constant, the amount of moisture supplied to the soil must just balance the quantity lost, *e.g.*, the quantity actually added has a *zero* value. Should these two processes not exactly balance one another, a tendency will be established which will in time become intensified, so that after a certain period the physical aspect of the country will be entirely altered.

It is, I consider, only in the years of abnormal rainfall that the additions more than balance the losses, and that the average level of the ground water is actually raised.

What exact effect a period of very low rainfall has is not quite so clear, but possibly the losses may not increase in the ratio expected. It must not be lost sight of that the present abundance of underground water may in part represent the result of gradual accumulation during the former period of higher rainfall.

Amount available.—So far yet we have not taken into consideration the disturbing effect of the artificial removal of water as a consequence of human occupation.

We may take the average depth at which water is found on sinking a well in this area at 50 feet; some wells in the district are over 100 feet in depth, and there is one example as much as 140 feet deep.

A certain number of wells have had to be deepened from time to time, as the water was removed from the rock and as the supplies had to be drawn from points further distant. The practical limiting depth, however, may be taken at 150 feet.

The whole of the moisture contained in any given volume of saturated soil cannot be entirely withdrawn; experiments show that even after several years of draining about 20 per cent. is still retained. After wells have served their purpose, boreholes may be employed to drain the lower levels, but it must be remembered that the pore-space in rocks diminishes as we descend, so that the advantage gained in depth will finally be set off by the diminished porosity of the water-bearing material.

The movement of water underground towards wells and boreholes is slow, and varies considerably for different materials; for average sandy soils and pressure gradients the velocity* of flow is from 1 to 2 miles per annum. The rate decreases very rapidly with diminished porosity, and in decomposed rock the velocity must be extremely small indeed.

It may therefore happen that a well will show a gradual falling

* C. Slichter, "Motions of Underground Waters." United States Geological Survey, Water Supply and Irrigation Papers, No. 67, p. 26, 1902.

off in its yield. This may be got over by sinking fresh wells, but they should be so far distant from one another that they do not interfere.

The effects of extensive and prolonged draining of the soil are becoming very marked in several countries, sometimes so much so as to give reasonable cause for alarm.

In Southern California* in the last ten years the level of the ground water has been lowered at various places from 30 to 90 feet over extensive areas.

This is worthy of special attention, because this portion of North America in certain respects resembles Bechuanaland, as the region is one of low rainfall and the flow in the rivers is lost in the sands of the plains which extend along the foot of the Sierra Nevada.

In London,† during the last 30 years, the level of the water in the chalk and lower tertiary sands has fallen a distance of from 40 to 60 feet; in this case, however, the drain upon the resources of the basin has been excessive.

Conclusion.—In the foregoing I have endeavoured to point out the various influences—some beneficial, others adverse—that affect the underground water supply, and though I may have given rather greater prominence to the latter, it is chiefly with the object of drawing attention to a matter of no small importance.

There is much need for extended study of the conditions for and against the accumulation of water, and of experiments in order to determine how great a proportion of the annual rainfall is actually available, and how this amount is affected by periods of abnormal rainfall or of unusual drought. Not only does this apply to Bechuanaland but to all parts of South Africa, though each district will have influences that will modify these problems.

As regards supplies in this area I think that we can only rely upon shallow wells and boreholes of no great depth. I have only come across a few spots where the conditions are apparently favourable for artesian supplies; but such occurrences are strictly limited, and the areas so favoured are of but small extent.

Wells have the disadvantage over boreholes in the matter of depth and cost, while in places where the soil is sandy and deep the walls may require supporting by means of cribs with linings of wood or sheet-iron; this has been done in some of the wells beyond Genesa.

Towards the Kalahari this difficulty may perhaps be overcome by the employment of drive-wells, *e.g.*, tubes perforated at their lower

* United States Geological Survey, Monograph xlvii., p. 427.

† Prestwich, "Water Supply of London," p. 189, 1895.

extremities and furnished with conical brass penetrating points. They are driven down through the sand until the saturated soil is penetrated. Over most of this area, however, the depth of soil is probably not sufficient to warrant their adoption.

In some of the valleys sub-surface dams might be built, and by that means the water, which under ordinary conditions makes its way slowly down below the river-bed, brought up to the surface. Such a dam is constructed by excavating a trench across the (dry) river-channel, extending it down to the bed-rock, and then filling it with masonry.

This system has been extremely successful in California, and there are numerous places here where similar dams could be built, *e.g.*, down the Molopo and Setlagoli Rivers.

With regard to boring for water I do not think that it is advisable to go beyond a depth of 400 feet; such few borings as have exceeded this do not yield any great supply.

The question of size of borehole is of no great importance; the advantage of a 6-inch hole over a 4-inch one is to a great degree imaginary, as their actual relative capacities have the ratio 100 to 95.*

In conclusion, I think that for many years to come the underground supplies will prove sufficient for average needs, although it is improbable that anything great will be done in the way of irrigation.

As a cattle-raising country this part of the Cape Colony is unequalled, and when the great tracts of ground, thickly covered with grass and bush and as yet unoccupied and unsurveyed, are considered, it is to be hoped that greater facilities and inducements may be given by the Government to persons desirous of settling here, so that the potentiality of this vast area may in the future become a reality.

* C. Slichter, *loc. cit.*, p. 85.